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Surface Water and Ocean Topography (SWOT) Mission

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Cross-over Calibration for hydrology: Why ? How ? Should you care ?

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Introduction

- A major component of the hydrology error budget is the systematic error (JPL error budget description, ref #D-79084)
- Cross-over calibration (XCAL) uses ocean coverage and inland interpolation to correct hydrology measurements
- Purpose of this talk : answer 3 questions about XCAL

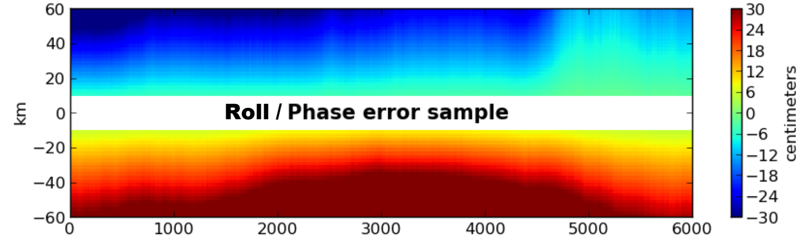
1 - Why ? (rationale of crossover algorithms)
2 - How ? (algorithms in a nutshell)
3 - Should you care ? (variability of residual errors)

Rationale for cross-over calibration

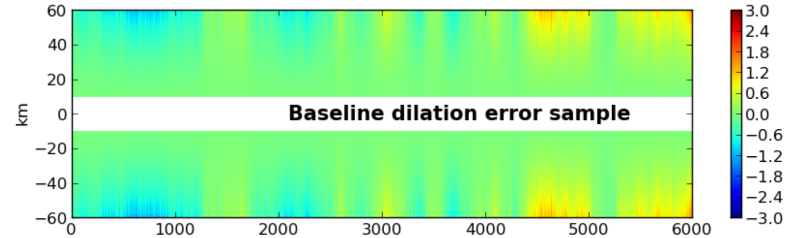
KaRIN’s systematic errors: example of roll

- To deliver good interferometric products, the relative position of antennas must be known within micro-meters (very hard)

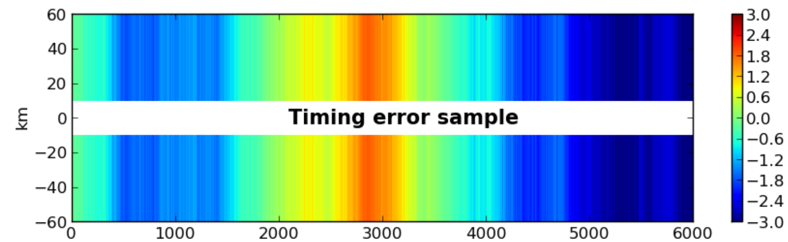
- Antenna roll angle is not perfect ?
  Linear cross-track error



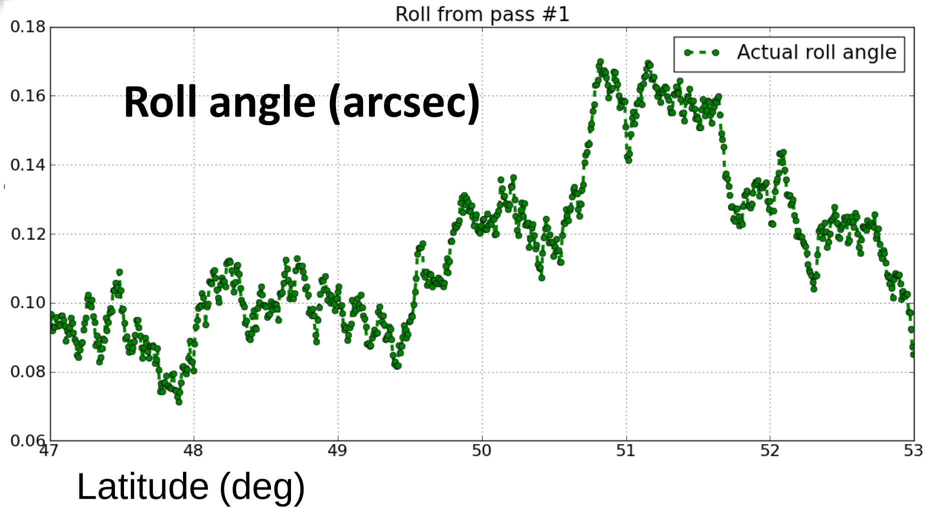
- Baseline length is not perfect ?
  Quadratic cross-track error



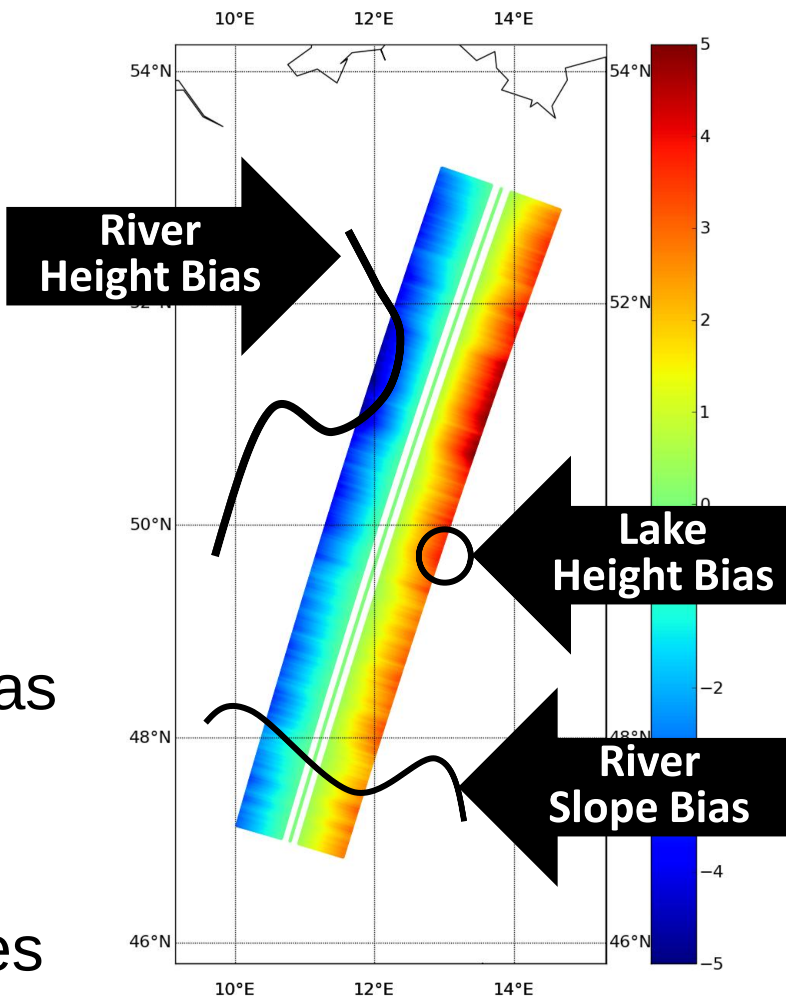
- Range timing bias in KaRIN ?
  Time-varying offset error



Example of roll errors for inland products



- For the small targets of hydrology: bias in water height or river slope
- Can be very different with each cycle
- Basically a random error in time series



Roll signature on topography (cm)

Reducing systematic errors: example of roll

If the unknown parameter (e.g. roll angle, timing bias) is perfectly calibrated, its signature on water height is removed

➡ The challenge is to calibrate relevant parameters as accurately as possible

- First level of correction w/ gyros, star-trackers and models…
- Residuals are still too high to meet the science requirements

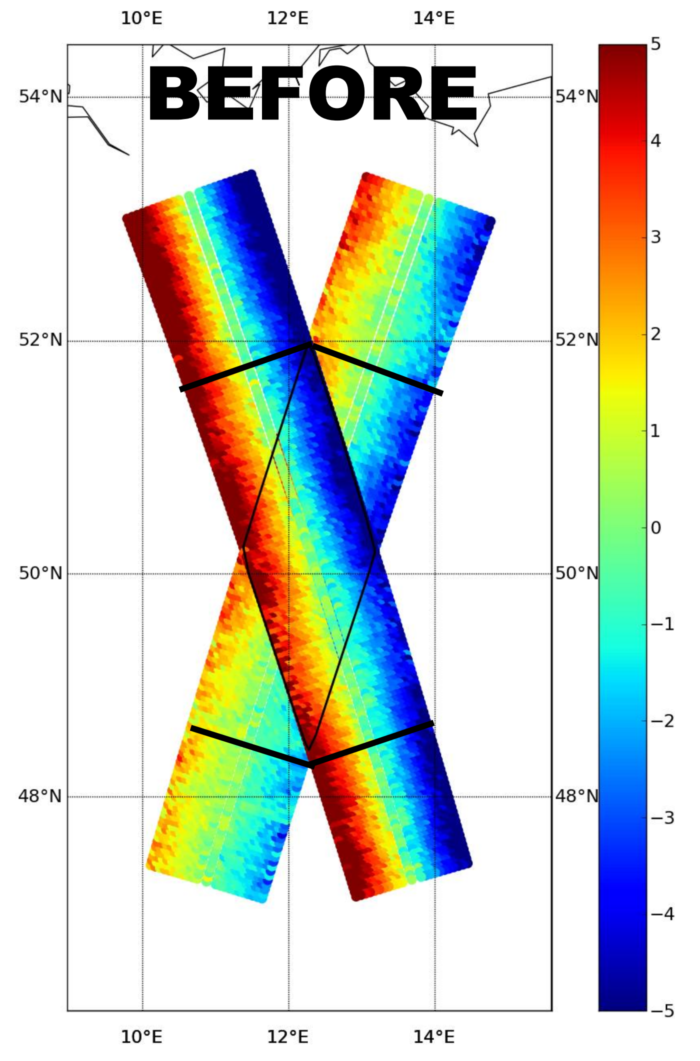
KaRIn Hydrology Error Component	Height Error [cm]	Slope Error [urad]	Comment
KaRIn Random	4.4	8.0	Height based on a $1km^2$ averaging area of water-only pixels; slope based on a 10 km downstream averaging of a 100 m river.
KaRIn Systematic cross-track errors after cross-over correction	7.4	1.7	Residual after cross-over correction; these are the RMS cross-track slopes (and associated height) for the entire along-track land pass.
KaRIn Systematic along-track height bias error	1.5	0.08	This is the RMS timing and dilation along-track height errors accumulated down to 0 Hz.
High Frequency errors	1.15	0.5	RMS of systematic errors > 6.5 Hz
(Unallocated margin, RSS)	1.23	0.31	
Total (RSS) Error Requirement	**8.9**	**8.2**	**Requirement**

- Need a 2^{nd} level of correction ➡ use of ocean-crossovers

Cross-over calibration in a nutshell

Example of roll XOVER calibration

- SWOT topography (LR on ocean) is skewed by uncalibrated residual roll
- When the opposite swath is visible (black diamond), roll is mitigated
- ~30.000 crossovers every 21 days
- Inland crossovers cannot be used (SNR and topography error, limited water coverage, layover)
- <u>Roll correction must be interpolated between ocean crossovers</u>



Example of XOVER diamond and local calibration

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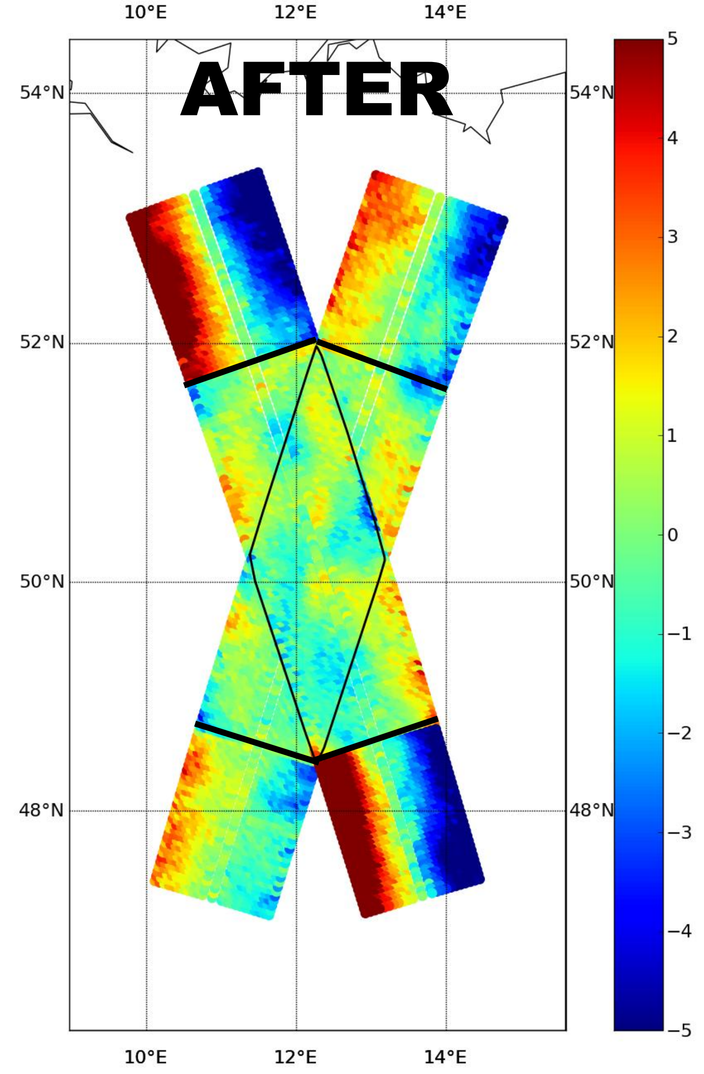
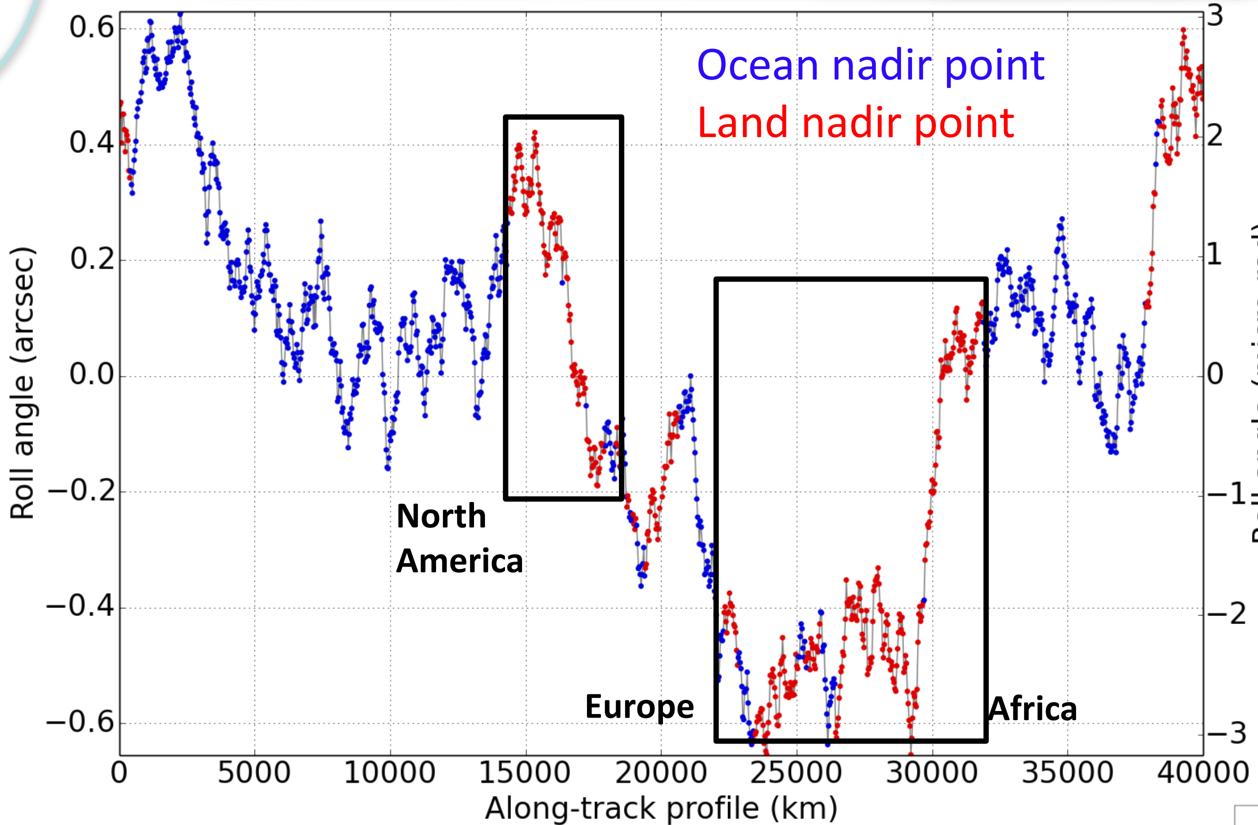
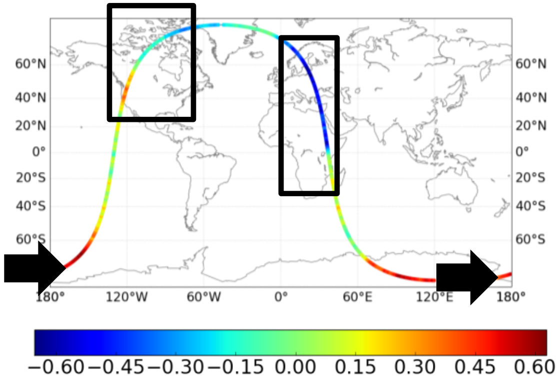


Example of XOVER diamond and local calibration

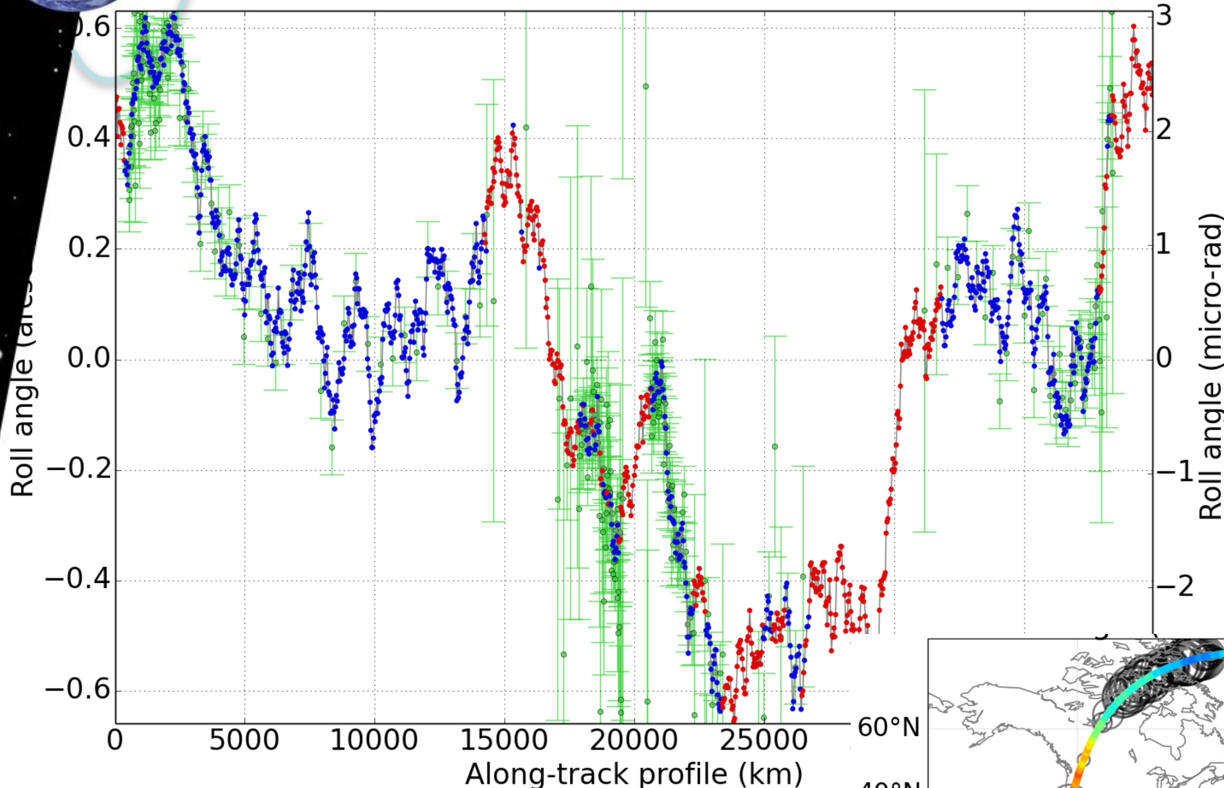
Sample of error for one revolution





- Combination of slow and rapid changes (K^{-2} law)
- Goal of calibration for hydrology is to mitigate the <u>long wavelength</u> error over inland segments

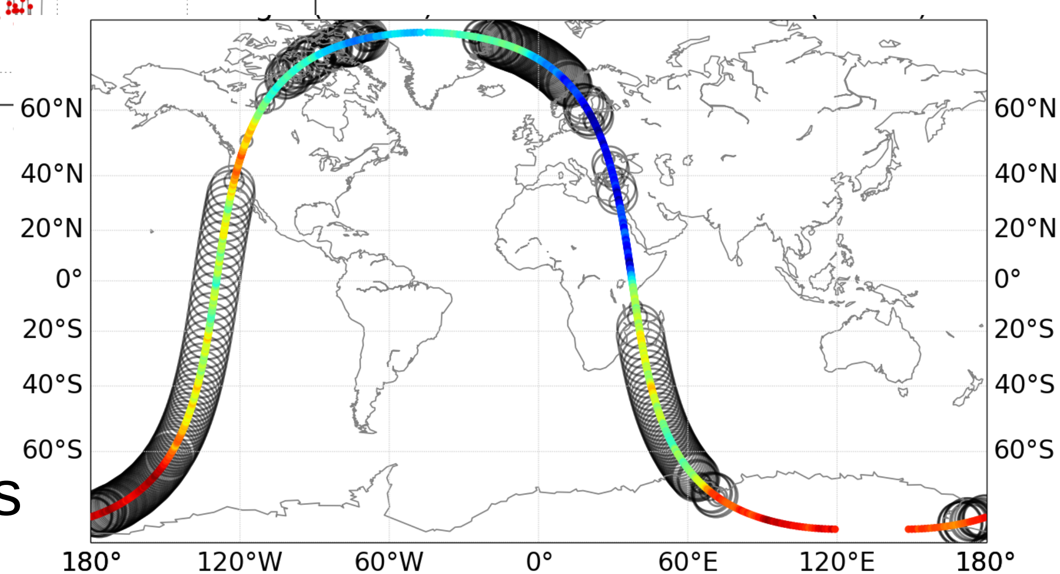
STEP1 - Inverse XOVER diamonds



Ocean **XOVER zones**

Green dot
& error bars

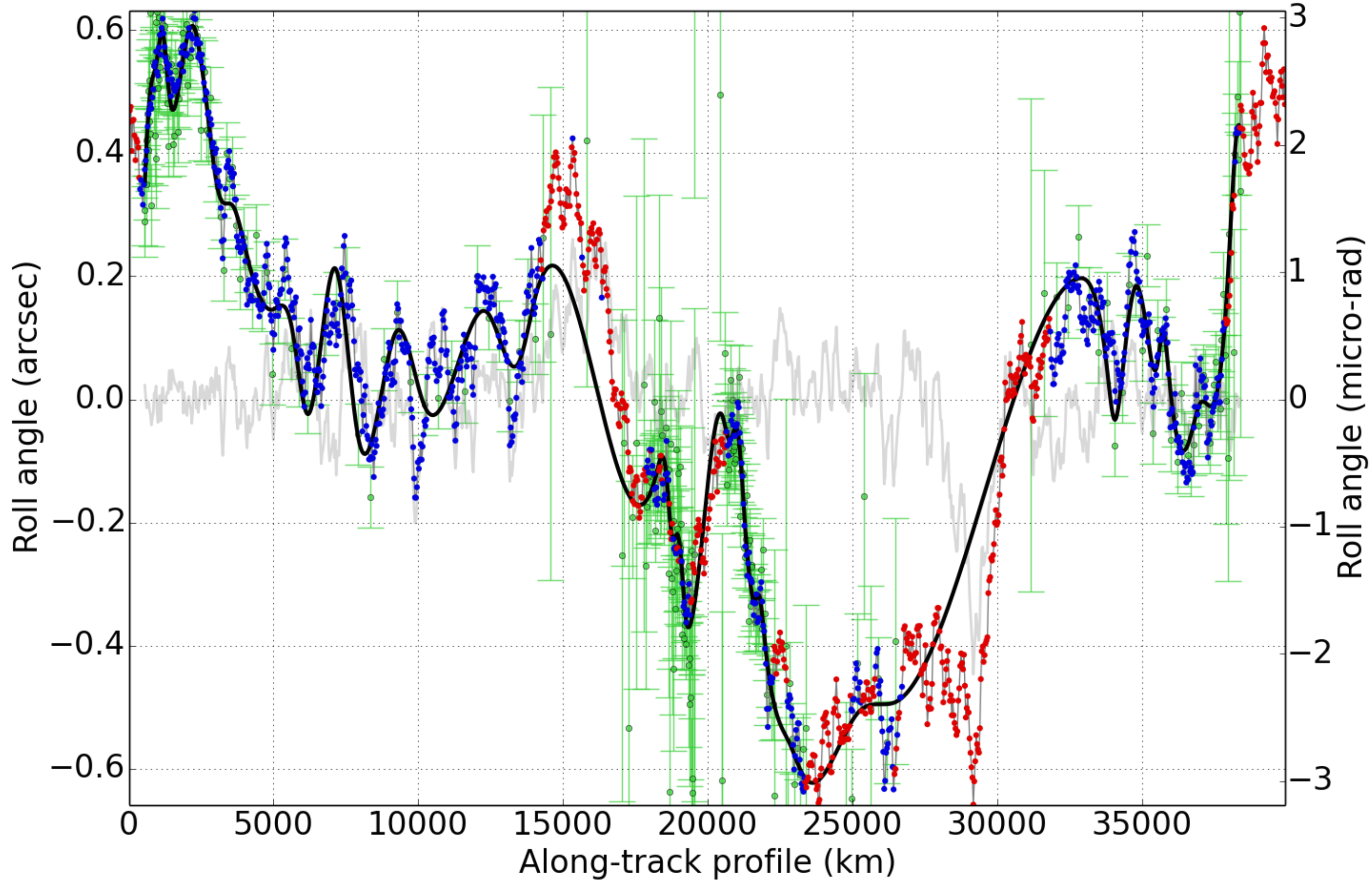
Black circles



- Roll is well observed in the open ocean
- No data for inland segments

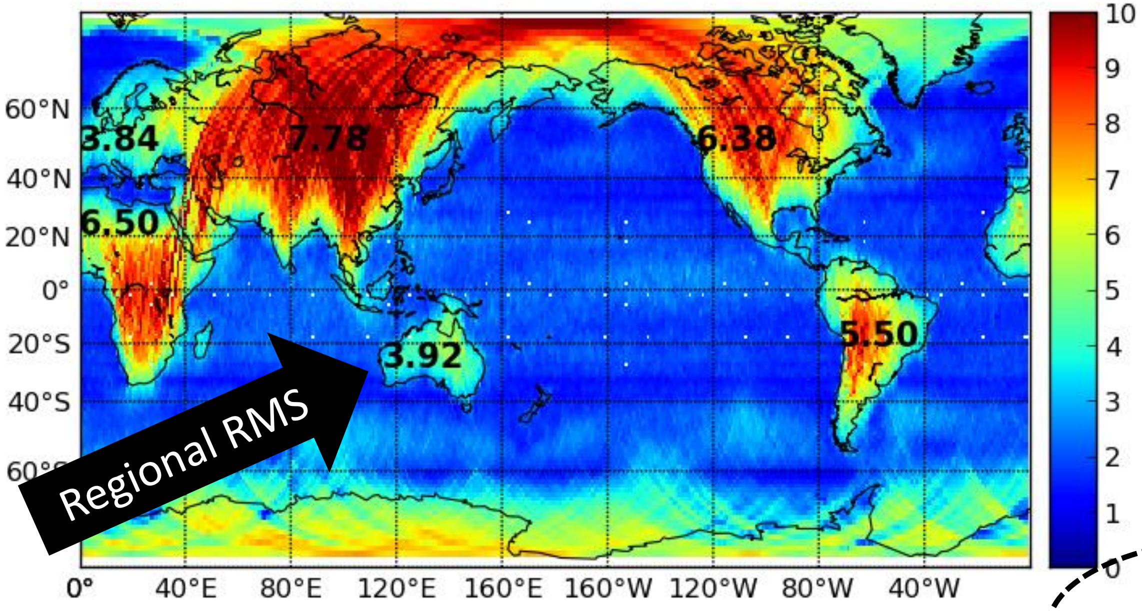
STEP2 - Interpolate calibration

- Interpolated correction (black, thick) and residual (gray, thin)
- Slow signals are well captured everywhere
- Inland error is substantially reduced
- Uncorrected residuals due to rapid roll events occurring inland



Variability of residual systematic errors

Water height performance (2-year simulation)



Residual topography error after calibration (cm RMS)

Global inland RMS: 6.33cm

- Hydrology requirement after calibration for topography is 7.4 cm RMS for roll and phase errors (from JPL D-79084)

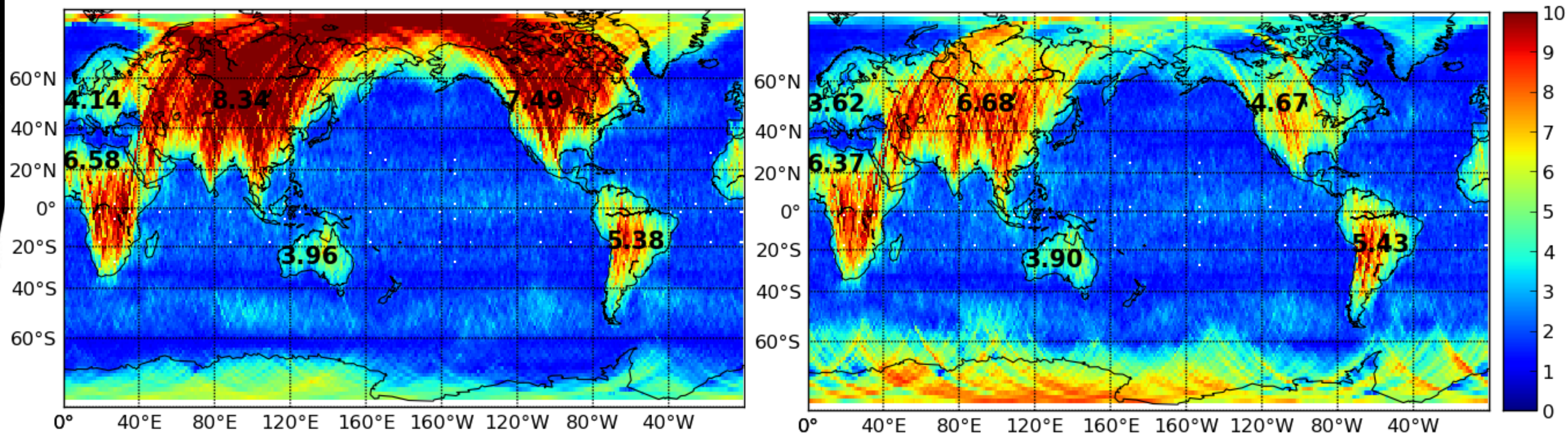
➡ Requirement is largely met in canonical scenario

- Large margins to account for idealized assumptions
- Spatial variability: Asia is challenging and the main contributor

Seasonal variability from sea-ice coverage

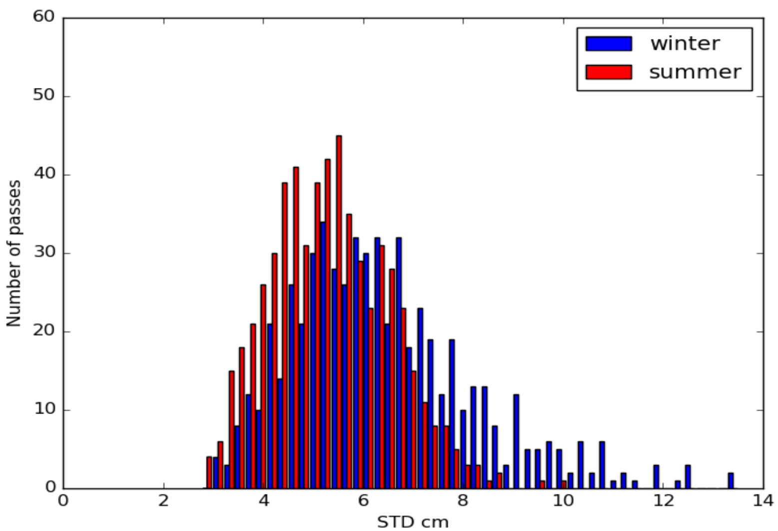
Jan-Feb-Mar

Jul-Aug-Sep



Inland RMS: 6.85cm

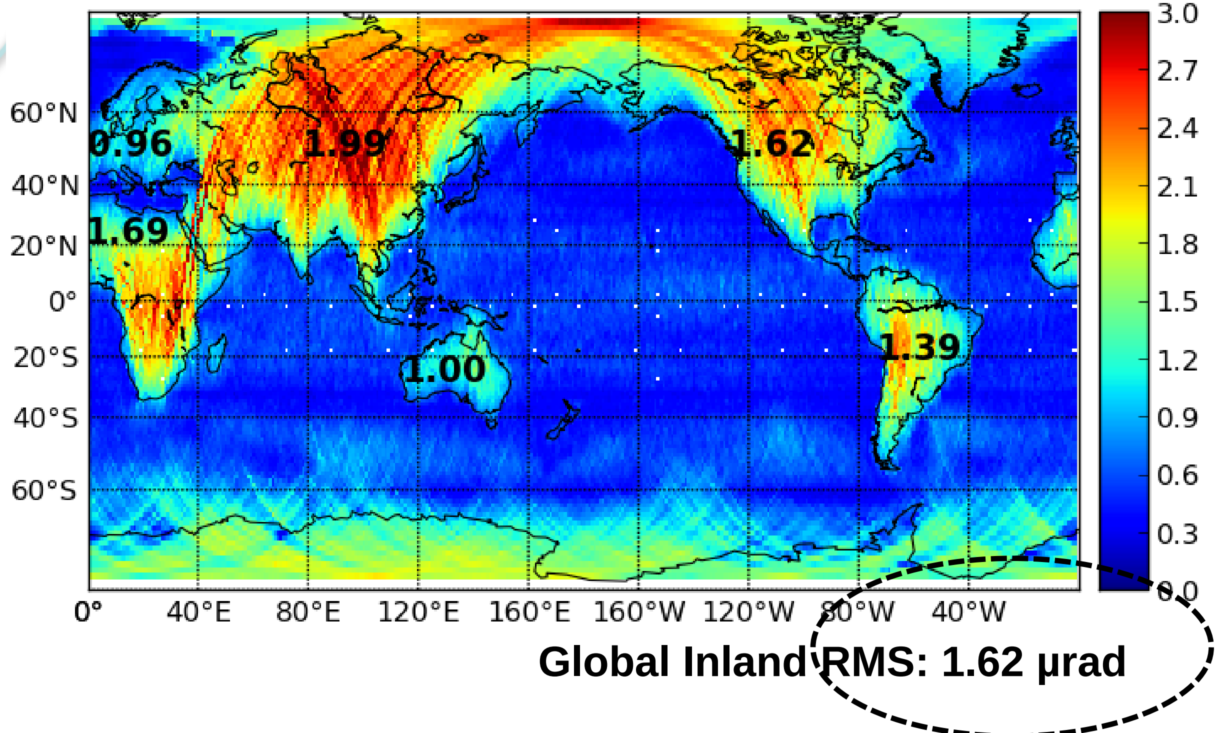
Inland RMS: 5.58cm



- Strong seasonnal variability
- Sea-ice bridges very long inland arcs with no ocean crossover : very high errors
- Non-freezing Norwegian sea helps Europe

➡ Calibration performance is primarily limited by long arcs with frozen seas (main target if more margins are needed)

Slope performance (2-year simulation)



Residual slope error after calibration (µrad RMS)

- Hydrology requirement after calibration for slope is 1.7 µrad RMS for roll and phase errors (from JPL D-79084)
- Requirement is met in canonical scenario
- Approximatively 10% margins w.r.t error allocation variance
- Measured only with cross-track slope (worst case scenario)
- Same space/time variability as height once XCAL is applied

Conclusions and outlook

Conclusions and outlook

- Hydrology requirements are met in canonical scenario
  - 6.33 cm RMS (25% margins w.r.t to allocated error variance)
  - 1.62 cm µrad (10% margins w.r.t to allocated error variance)
  - Hydrology requirements also met in near real time (see backup)
- Error variability might affect local studies of the science team
  - High geographical variability (long inland arcs are challenging)
  - High seasonal variability due to sea ice coverage
- Way forward
  - Add this variability in the hydrology science simulator
  - Transition XCAL from prototype to operational software
  - Explore optional algorithms (better products) as part of ST work
    - Use crossovers on big lakes, use static targets, use corner reflects (for long inland arcs)
    - Use other algorithms from Dibarboure et Ubelmann (2014)
    - Use better propagation schemes

Backup slides

REFERENCES

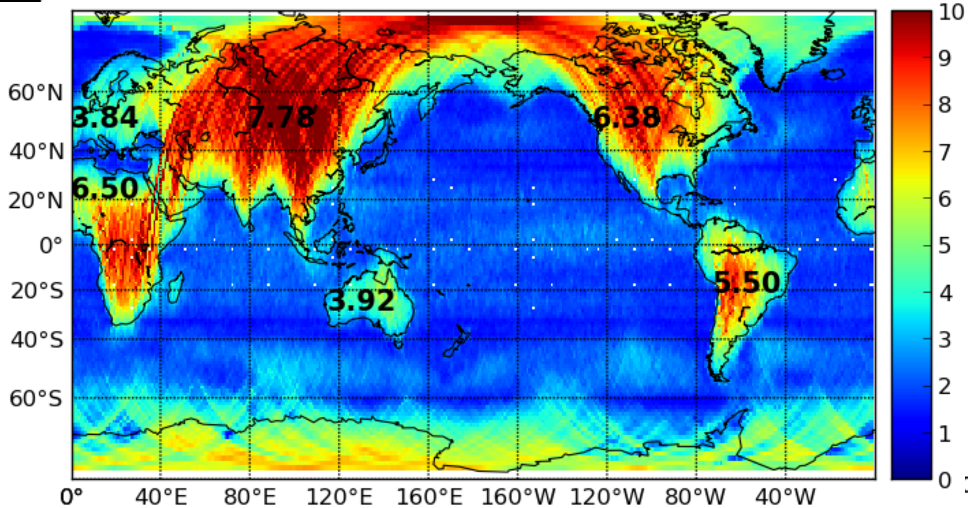
• Dibarboure, G., & Ubelmann, C. (2014). Investigating the Performance of Four Empirical Cross-Calibration Methods for the Proposed SWOT Mission. Remote Sensing, 6(6), 4831-4869.

• Dibarboure, G., Labroue, S., Ablain, M., Fjortoft, R., Mallet, A., Lambin, J., & Souyris, J. C. (2012). Empirical cross-calibration of coherent SWOT errors using external references and the altimetry constellation. *Geoscience and Remote Sensing, IEEE Transactions on*, *50*(6), 2325-2344.

• Fu, L. L., & Ubelmann, C. (2014). On the transition from profile altimeter to swath altimeter for observing global ocean surface topography. *Journal of Atmospheric and Oceanic Technology*, *31*(2), 560-568.

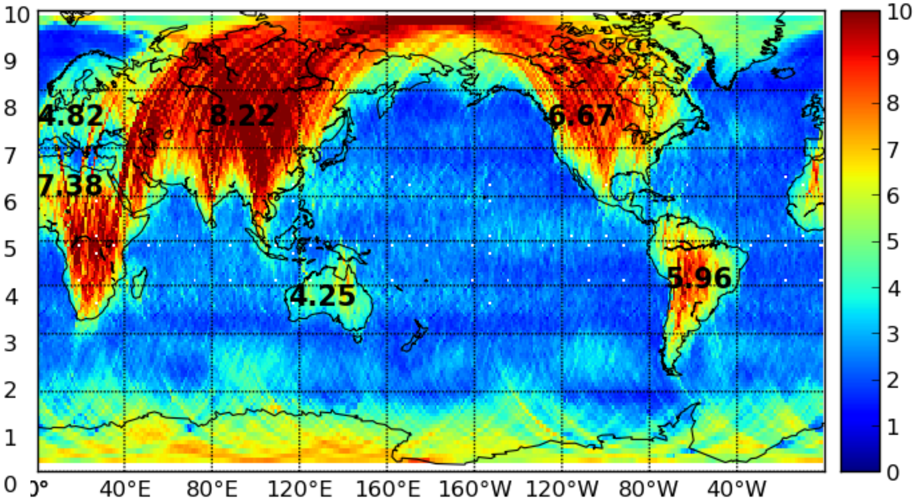
Delayed time versus NRT

Delayed Time / Offline: using all XOVERs



Inland RMS: 6.33cm

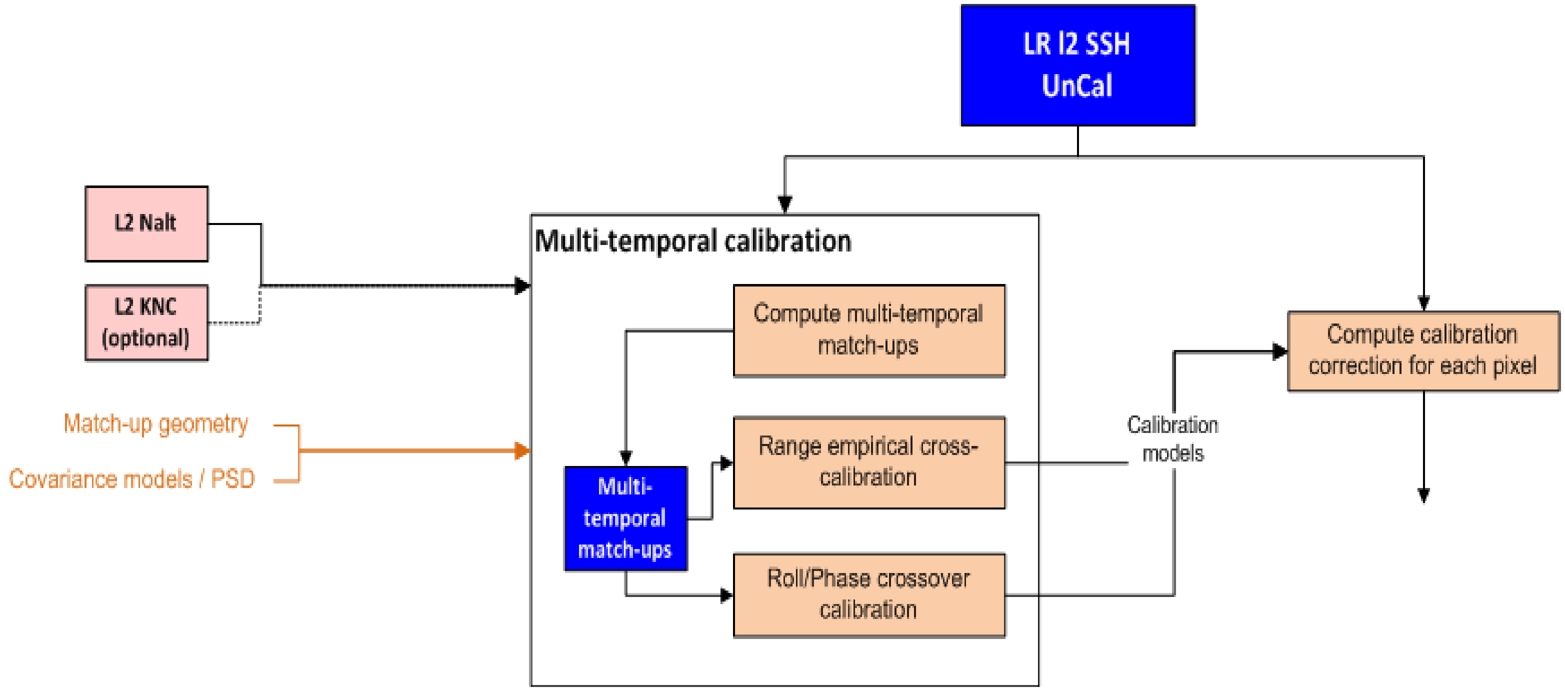
NRT: using only past XOVERs



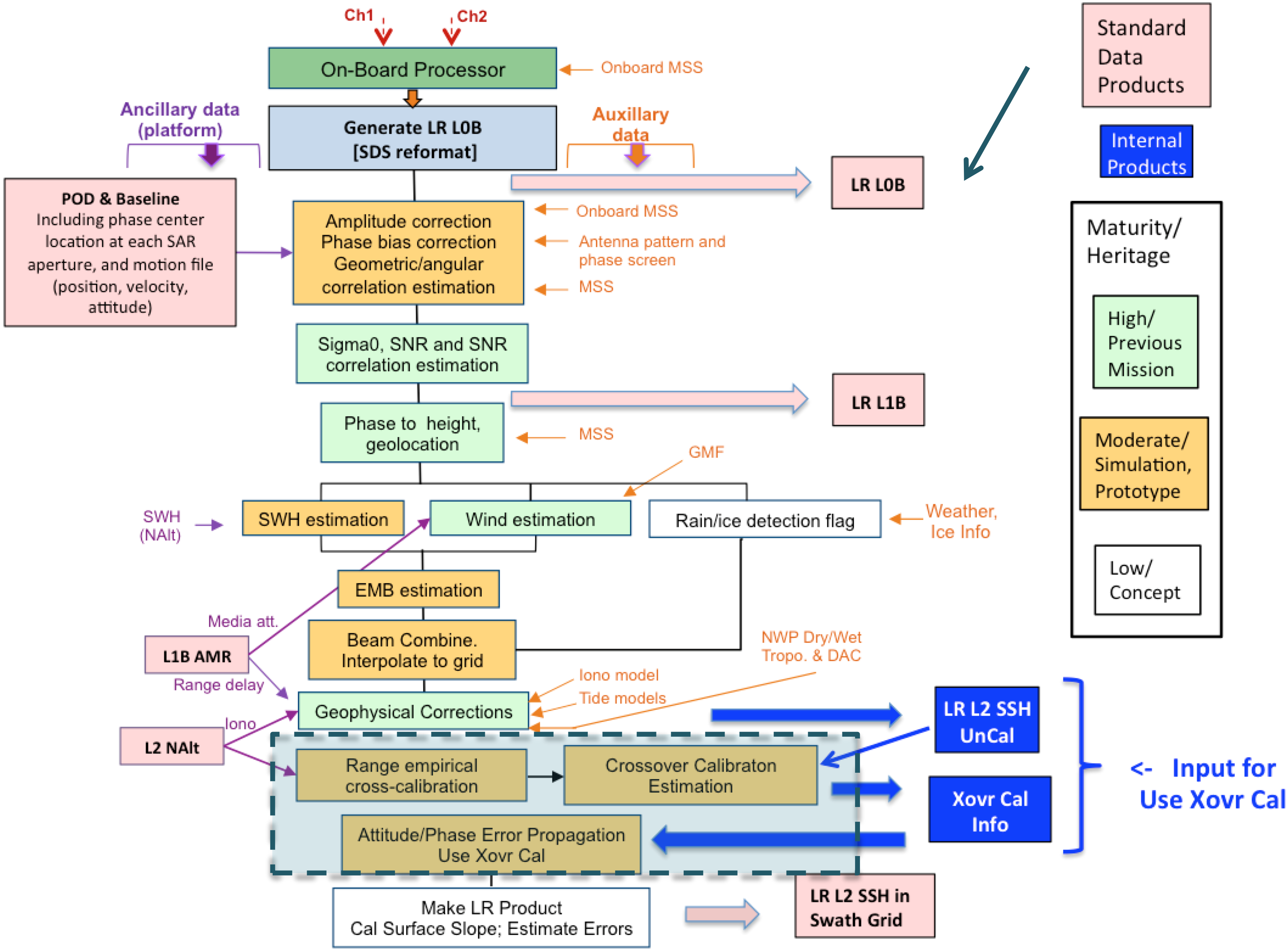
Inland RMS: 6.87cm

- Global Hydrology requirement is met in NRT
- Approx 14% margins in NRT (w.r.t to error allocation variance)
- Performance still dominated by Northen arcs and frozen seas
- Good NRT performance due to 10-day sub-cycle of the science orbit

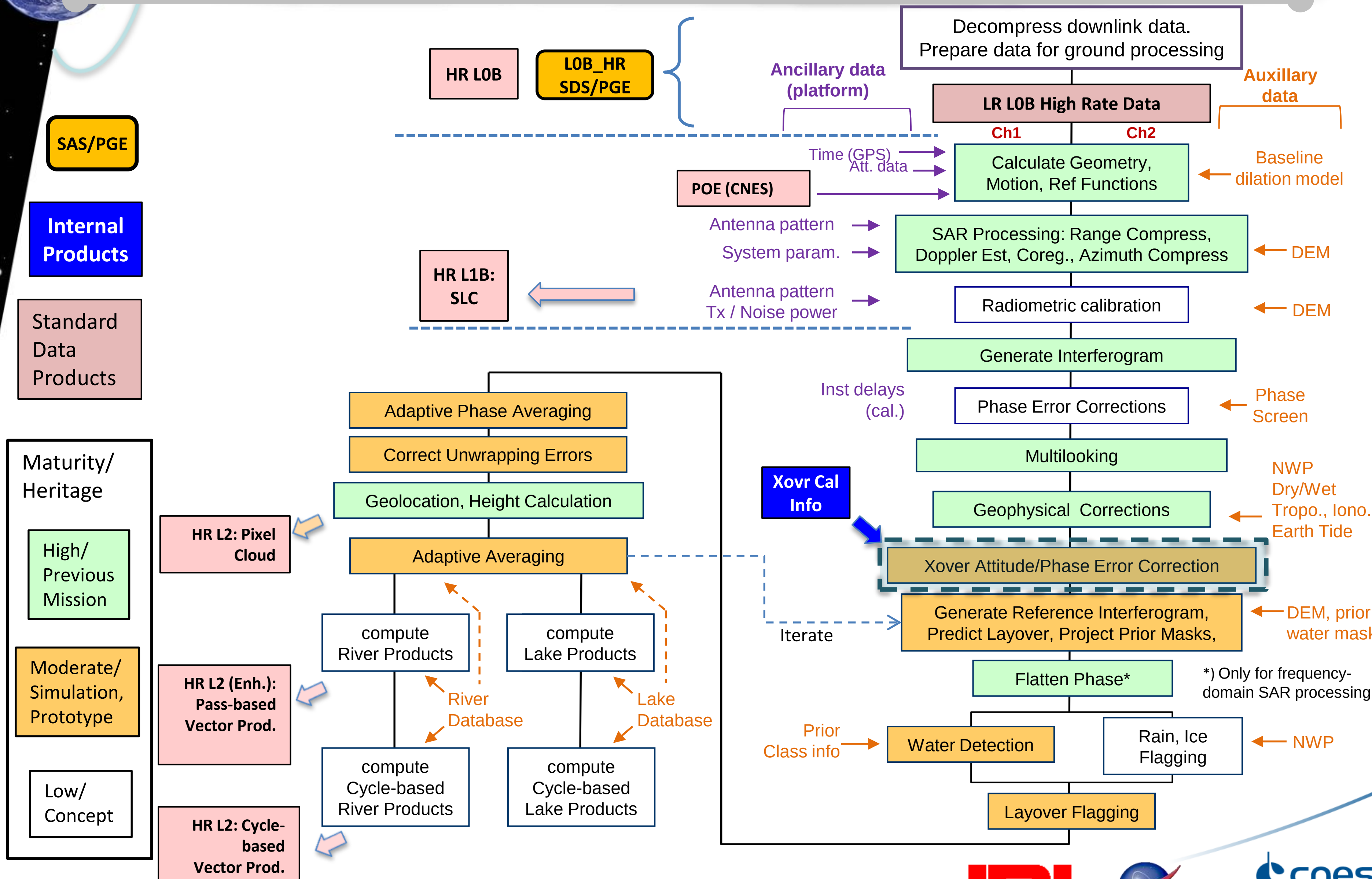
KaRIn LR/Ocean Processing Functional Flow



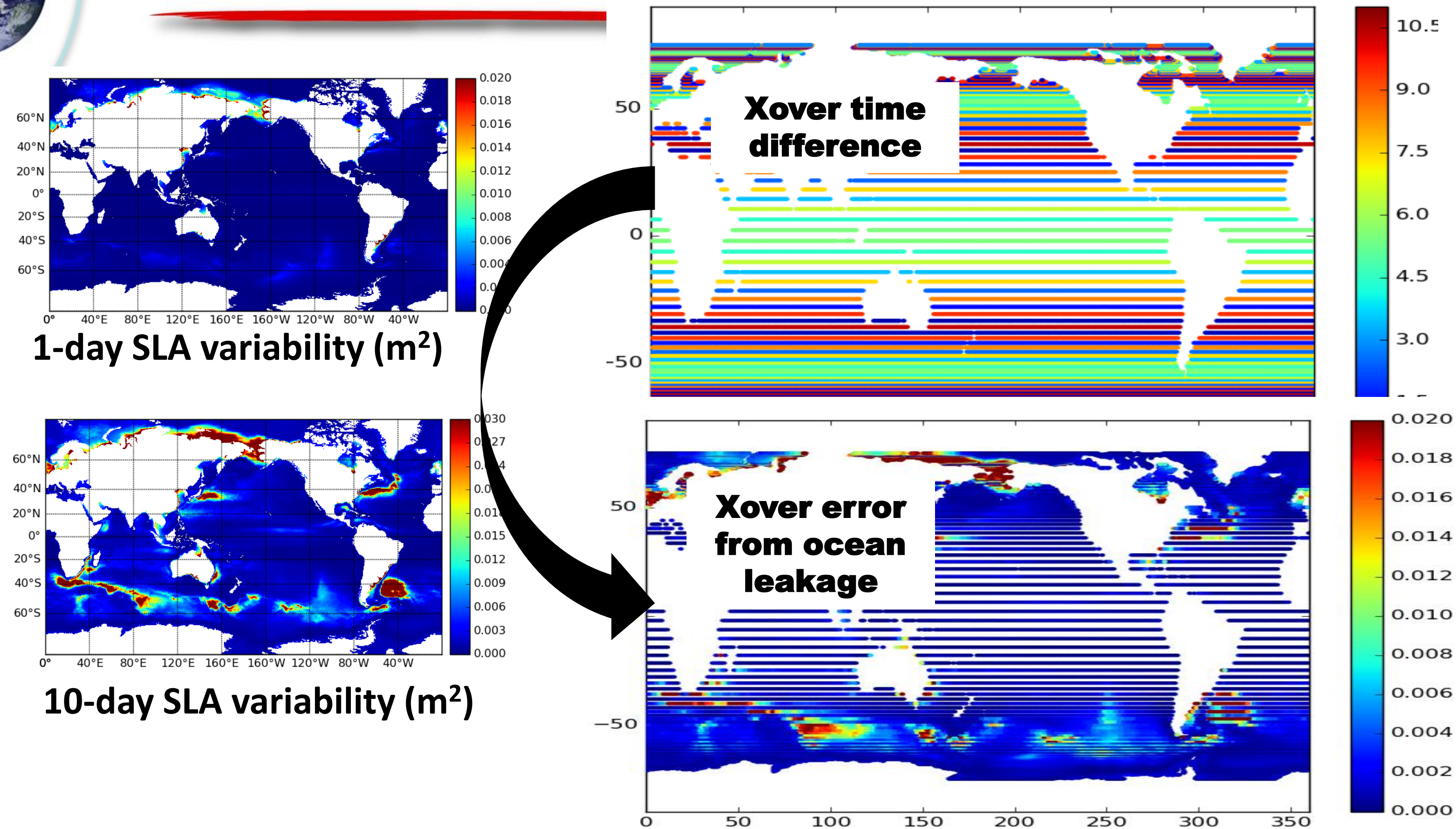
KaRIn LR/Ocean Processing Functional Flow



KaRIn HR/Hydrology Processing Functional Flow

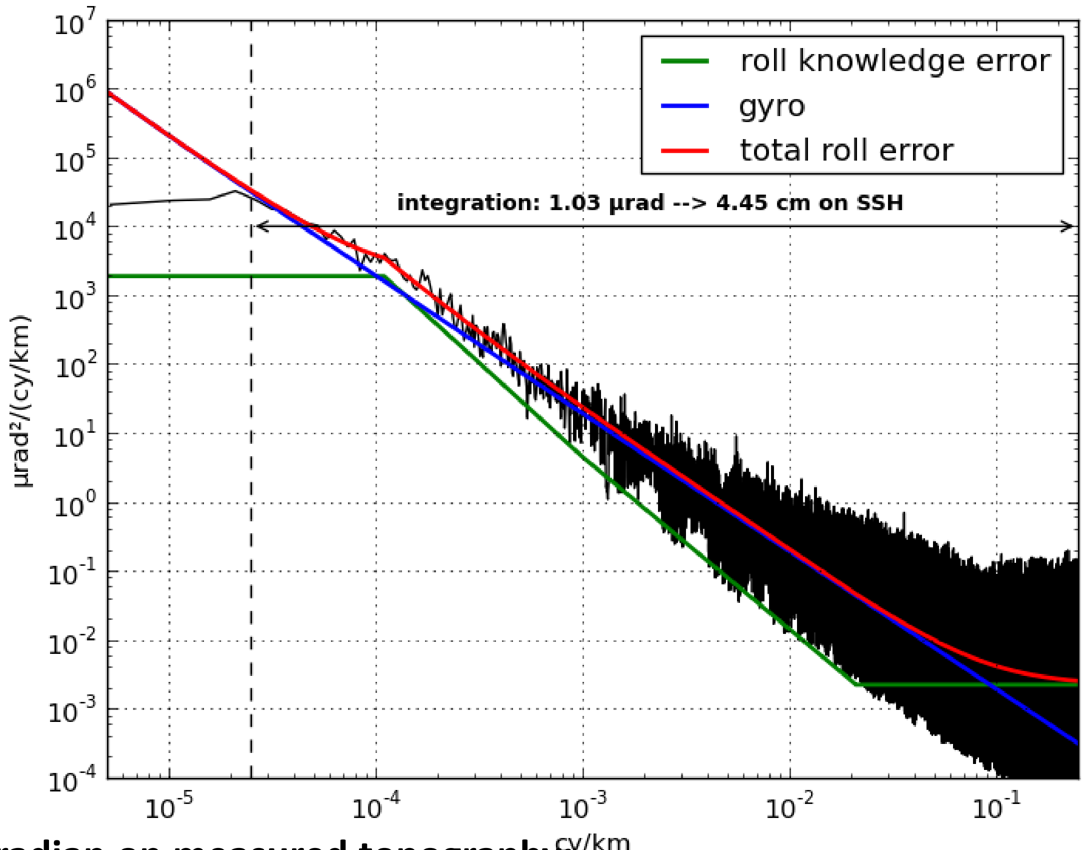


Ponderation with Xover expected Ocean-leakage



- Important to weight XOVERs with Ocean slope variability **at the crossover difference time**
- Variability is generally high near the coasts (coastal Kelvin waves ans wind effects <10.5 days)
- In our canonical case, the GLORYS dataset provides a perfect parameter for calibration
- **Before launch: necessary to build this input parameter from past and present altimetry**

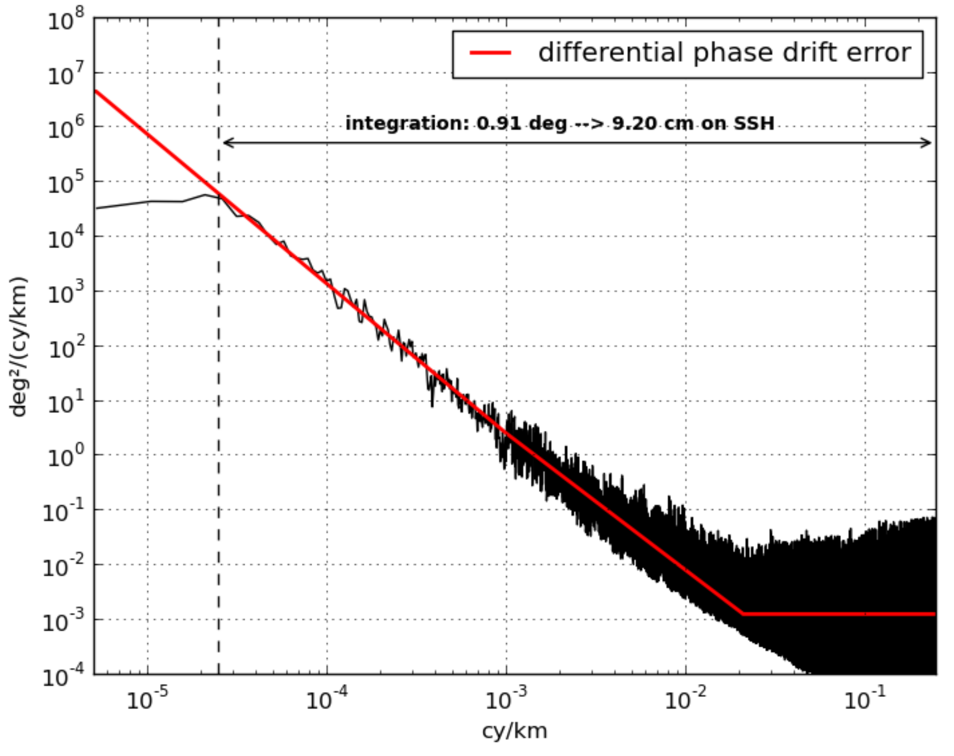
Roll error



Arcsec to microradian on measured topography:

```
rollPSD1 = numpy.array(fid.variables['rollPSD'][:])*(1./3600*pi/180*1e6)**2  # arcsec**2 to urad**2
rollPSD2 = numpy.array(fid.variables['gyroPSD'][:])*(1./3600*pi/180*1e6)**2  # arcsec**2
PSroll1=(rollPSD1)*(1+const.sat_elev/const.Rearth)**2 # microrad**2
PSroll2=(rollPSD2)*(1+const.sat_elev/const.Rearth)**2 # microrad**2
PSroll=PSroll1+PSroll2 # microrad**2
```

Phase error



Deg to microradian on measured topography:

PSphase=phasePSD*(pi/180*1e6)**2 *((1/(const.Fka*2*pi/const.C*const.B)*(1+const.sat_elev/const.Rearth)))**2 # microrad**2